Artificial recharge and water conservation opportunities for the Lonepine Aquifer, Northwestern Montana

Submitted to the Eastern Sanders County Conservation District
by Ginette Abdo
Montana Bureau of Mines and Geology

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Executive Summary

The Lonepine aquifer is the major source of groundwater in the Little Bitterroot Valley. Since agriculture is the mainstay of the valley, groundwater resources are important for sustaining the economy. Groundwater conflicts have been documented since the early 1900's when the first wells were drilled and long-term groundwater declines indicate that withdrawals exceed recharge to the Lonepine aquifer. Groundwater conservation techniques and an artificial recharge scheme were examined to determine their potential to increase water levels in the Lonepine aquifer.

Groundwater conservation can increase water levels in the aquifer and is a cost effective alternative to artificial recharge. About 25 percent of the wells completed in the Lonepine aquifer are flowing – these wells are found along a portion of the Little Bitterroot River. Conservation efforts that include repairing faulty valves and casing, reducing or eliminating flows during non-beneficial use times, and techniques to either insulate the wellhead, install valves and/or seal groundwater off below the frost line can enhance groundwater resources. Efficient irrigation practices are also a form of conservation and can reduce groundwater wastage by up to a 30 percent.

Artificial recharge is another means of increasing water levels in the aquifer. However, costs can be prohibitive and much more expensive compared to groundwater conservation techniques. Bacteria and most likely viruses exist in the surface water system and there is the potential for the transport of these organisms in the subsurface if surface water is introduced into groundwater. Changes in water chemistry may be produced by mixing water in an oxidized state (surface water) with water in a reduced state (groundwater). This can result in microbial growth and iron precipitation causing clogging of the recharge wells, thereby reducing the efficiency of artificial recharge.

Groundwater conservation techniques should be implemented before any artificial recharge schemes are considered. The long-term benefit of groundwater conservation will help ensure that this resource will be available for future generations, thereby, preserving the economic foundation of the valley.

1.0 Introduction

The Lonepine aquifer is the main source of groundwater in the Little Bitterroot Valley located in northwestern Montana. Groundwater is used most intensively for irrigation but also supplies domestic and stock needs throughout the valley. The aquifer ranges in thickness from 7 to 60 feet and consists of very permeable sands and gravels with transmissivities ranging from 16,700 to 80,000 ft^2/day. The aquifer is under artesian pressure as a result of a thick sequence of overlying Glacial Lake Missoula silts and clays.

Donovan (1985) examined the hydrogeology of the Lonepine aquifer and identified long-term water level declines that ranged from 0.7 to 1.1 feet per year between 1970 to 1977 and 2.0 to 2.5 feet per year between 1981 and 1985. Based on long-term water level declines, increased competition for water by existing users, and the potential demand for additional aquifer development, Donovan and Noble (1986) developed a proposal to artificially recharge the Lonepine aquifer. The proposed recharge project would determine the effectiveness, technical feasibility, and the operational/maintenance requirements of injecting excess water from the Little Bitterroot River into the Lonepine aquifer using injection wells. The proposal was submitted to the Montana Department of Natural Resources and Conservation and to the U.S. Bureau of Reclamation.

1.1 Objectives

The objective of this report is to examine the feasibility of the artificial recharge concept proposed by Donovan and Noble (1986) using updated hydrogeologic information collected by Abdo (1997). Abdo characterized the hydrogeology of the Little Bitterroot Valley and compared her data with that of Donovan (1985). Included in the following report are water quality and groundwater level information collected by Abdo (1997) and her discussion of the effects of sealing a free-flowing well on the hydrogeologic system. Because surface water was the proposed source of artificial recharge, surface-water quality was compared to groundwater quality. The effects of groundwater conservation on the hydrogeologic system were also examined and alternatives are presented to help conserve the groundwater resources in the valley.

1.2 Location

The Little Bitterroot Valley is located approximately 13 miles west of Flathead Lake and 73 miles northwest of Missoula, Montana (Figure 1). The valley trends north - northwest and is drained by the Little Bitterroot River. The entire length of the river is approximately 63 miles and flows south and then east into the Flathead River near Sloan, Montana. Rainfall and runoff from snowmelt replenishes the river. The valley is approximately 3.0 to 4.5 miles wide north of Hot Springs Creek; south of creek it narrows to 2.0 to 3.5 miles. The Salish Mountains, which reach elevations of approximately 5,700 feet above sea level, border the valley on the east and north. The mountainous area to the west is part of the Lolo National Forest and reaches elevations about 7,500 feet above sea level.

Two sites were proposed to demonstrate the feasibility of injecting surface water to artificially recharge the groundwater. The first (Phase A) was a small scale demonstration site located approximately three-quarters of a mile northwest of Lonepine, Montana (Figure 1). The second site (Phase B) was to be an expansion of the first and would have been a wellfield located south of the Lower Dry Fork Reservoir (Figure 1).

1.3 Climate

The Little Bitterroot Valley is one of the most arid parts of northwestern Montana with an average annual rainfall of 14.60 inches, based on data collected at the Hot Springs weather station (1970-1985, 1988-1990). The driest year on record was 1979 with precipitation totaling 9.84 inches (Figure 2); during the wettest year, 1980, precipitation totaled 20.10 inches. March, April, July and August are typically the driest months; May, December and January are the wettest. Precipitation varies throughout the valley as a result of orographic effects from the surrounding upland areas. The upland areas are cooler and receive as much as 20 to 30 inches of annual precipitation (Natural Resource Conservation Service, 1975). Average seasonal snowfall in the valley ranges from 25 to 50 inches, with 100 to 300 inches occurring in the uplands (Natural Resource Conservation Service, 1975). Mean average annual temperatures range from 7 to 10°C (45° to 50°F) with monthly average temperatures in the summer of 21°C (70°F) (Donovan, 1985).

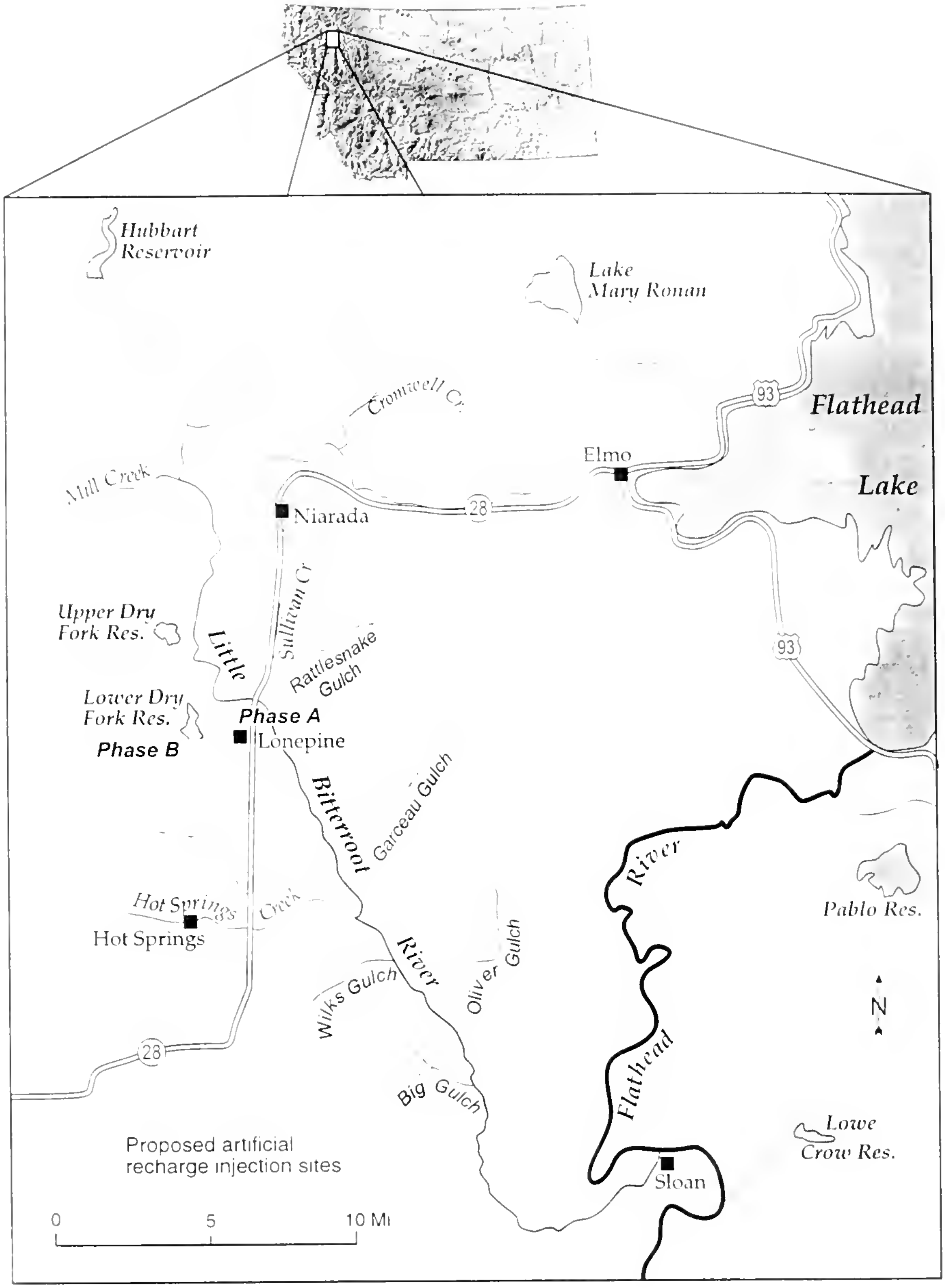

Figure 1. Location of the Little Bitterroot Valley and proposed artificial recharge sites.

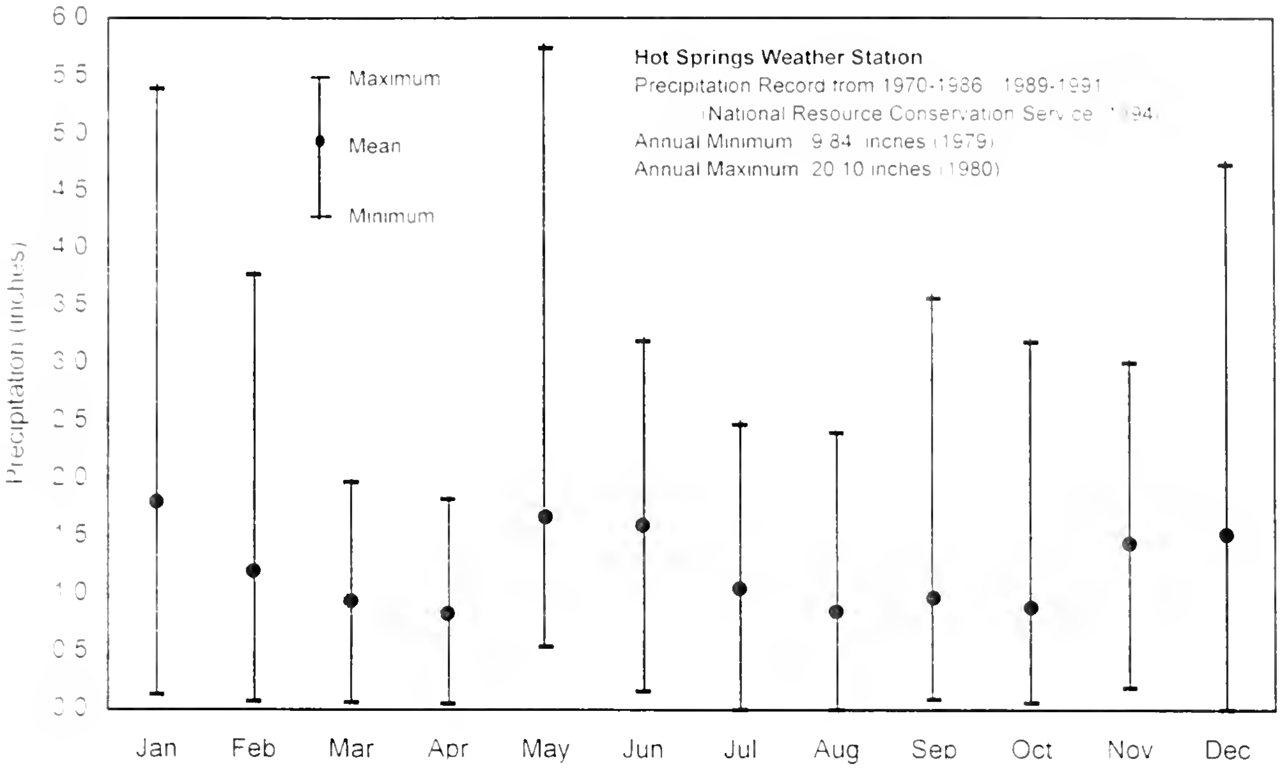

Figure 2. Precipitation data from the Hot Springs, Montana weather station

1.4 Background

Groundwater and surface water are critical resources that support the agricultural economy. Along the Little Bitterrot River, flowing wells were encountered during the early development of the valley. Figure 3 shows that the majority of wells were drilled from the early 1900's to the 1950's. Well interference problems were noted soon after the first wells were drilled. As a result, water use and supply questions immediately arose. For at least the last 25 years, groundwater withdrawals have exceeded recharge to the aquifer. The limited number of wells drilled for irrigation in recent years is probably due to the objections of current water users to new groundwater development.

During the dry years, when more intense irrigation is necessary, aquifer pressures are the lowest (Donovan, 1985). Approximately 90 acre-feet/day is appropriated from the Lonepine aquifer during the irrigation season (April - September) and about 37 acre-feet/day during the non-irrigating part of the year (Abdo, 1997).

Surface water supplies from the Little Bitterroot River are also used for irrigation purposes. A canal system, known as the Flathead Irrigation Project (FIP), is owned and operated by the Bureau of Indian Affairs and obtains water from the river and its tributaries. Water for the system is obtained from runoff that is stored in Little Bitterroot Lake (capacity 26,400 acre-feet) and the Hubbart Reservoir (capacity 12,125 acre-feet). Water from the Little Bitterroot River is diverted from the river via a canal system to fill the Lower Dry Fork reservoir near Lonepine, Montana (capacity 3856 acre-feet) (Figure 1). The Upper Dry Fork Reservoir (capacity 2814 acre-feet), located approximately 2 miles above the Lower Dry Fork Reservoir, is fed by runoff from Alder Creek, a tributary to the Little Thompson River. The water is gravity fed to ranches via a canal system; delivery quotas are set at an annual users meeting.

To augment groundwater supplies and to reverse long-term water level declines, Donovan and Noble (1986) proposed to artificially recharge the Lonepine aquifer. The proposal consisted of two phases. Phase A was to be a pilot injection site that consisted of injecting up to 3 acre-feet/day of water into a pre-existing well (Well 211) drilled in 1942 that is owned by the FIP (Figure 4). The source of the injection water would be excess runoff from the Little Bitterroot River obtained between February and May after the FIP reservoirs were full and instream flow requirements for the river have been met. The proposal stated that "Injection will

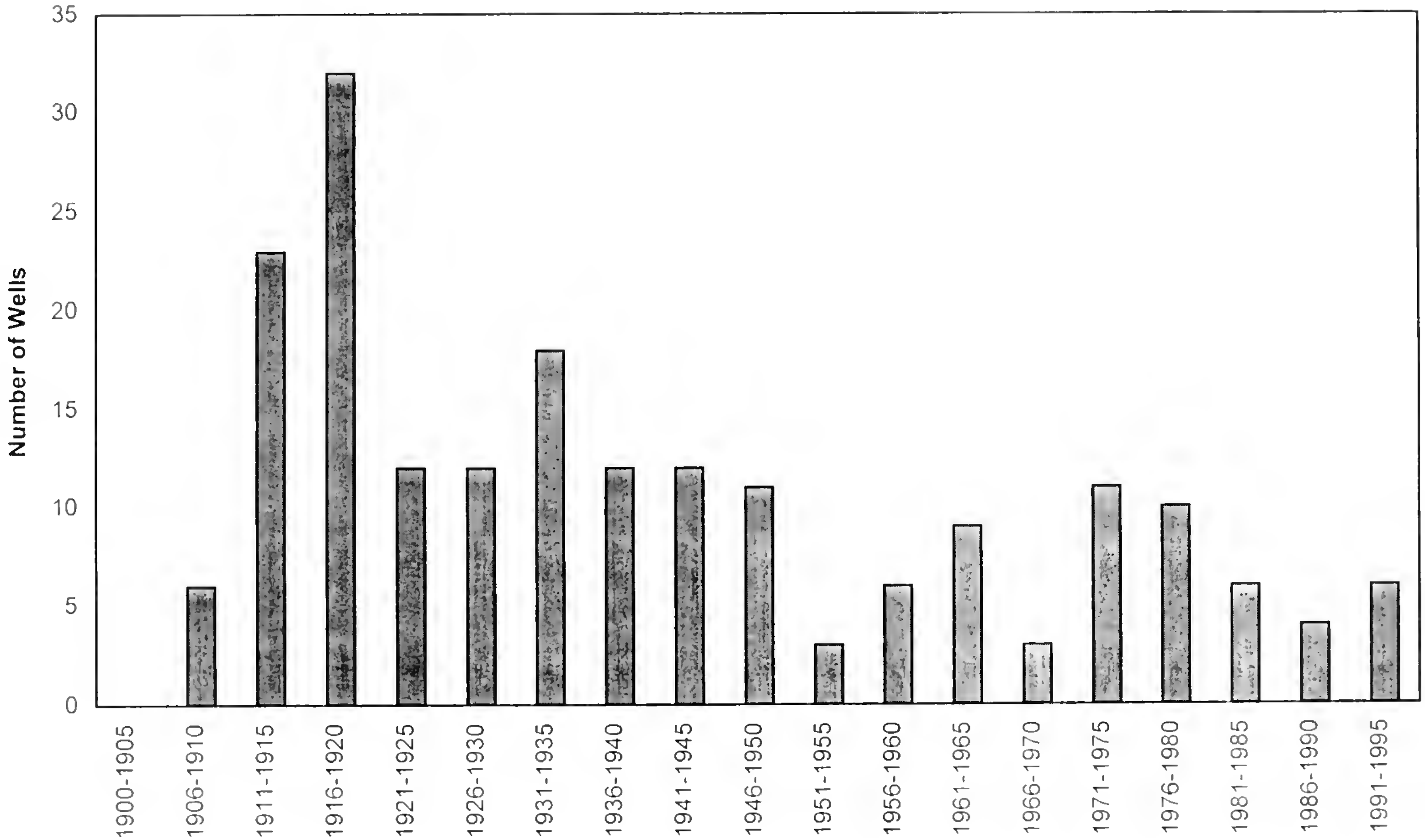

Figure 3. Number of wells drilled in the Lonepine aquifer per five year interval.

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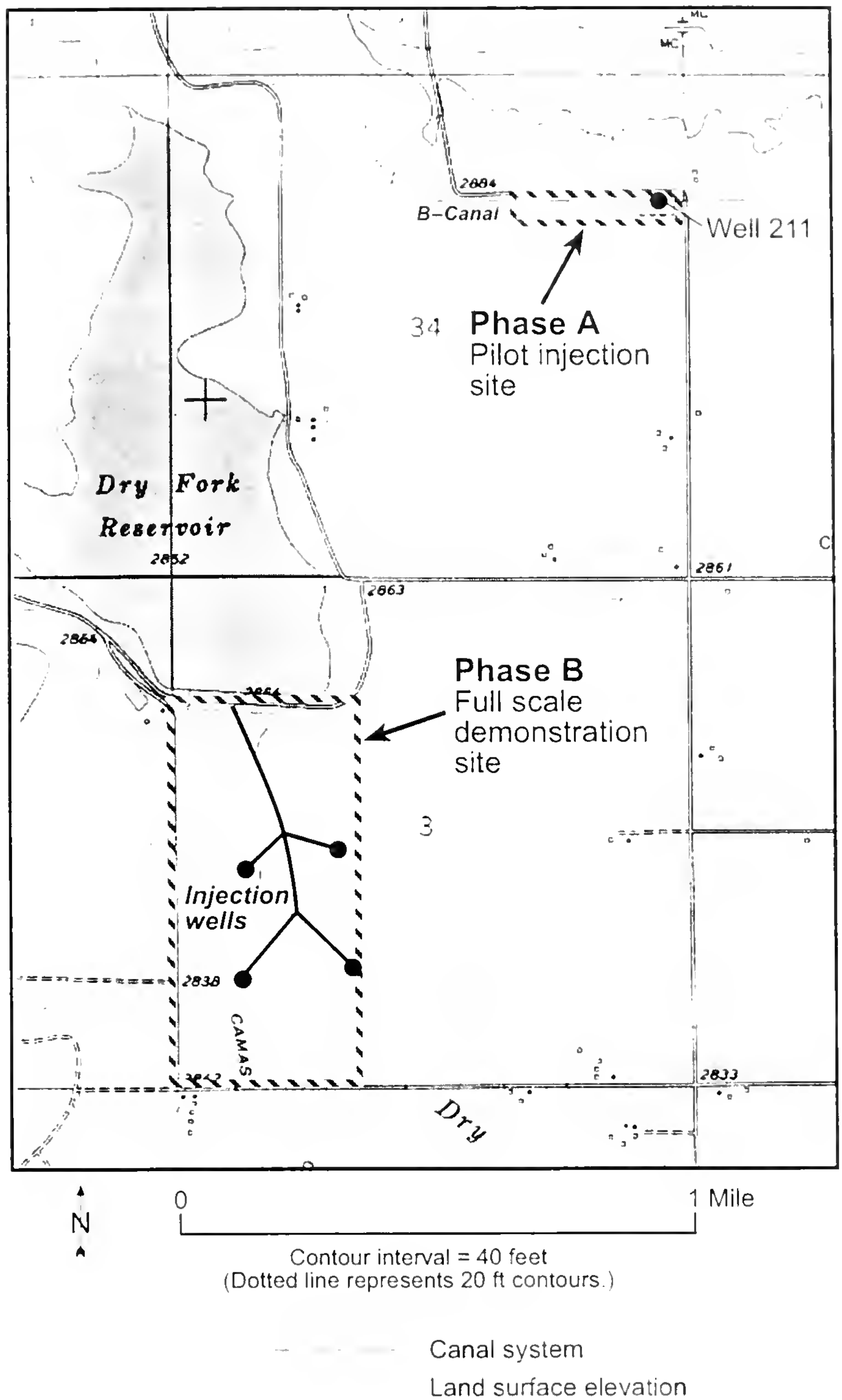

Figure 4. Location of Phase A and B of the artificial recharge proposal.

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take place without aeration or cascading of water and under a positive pressure of no greater than 30 feet." The water would be transported to the well by an existing FIP canal (B canal) and sediment would be removed in the canal by settling in combination with filtration through a filter bed in a sediment removal gallery. The sediment removal gallery would have a capacity of at least 1600 cubic feet of water and an area of 800 square feet. Phase A pilot project would have evaluated the technical feasibility, maintenance requirements and the water-quality impacts on the aquifer.

The second part of the proposal (Phase B) was to demonstrate the feasibility of injecting up to 7 acre-feet/day of excess water into 4 high capacity injection wells installed south of the Lower Dry Fork Reservoir (Figure 4). Water for the injection would be siphoned from the Lower Dry Fork Reservoir and sediment would be removed by settling only.

Groundwater monitoring was proposed for both phases of the project. Data from ten monitoring wells, six of which would have been installed as part of the proposed project, would have been collected and evaluated to allow a quantitative assessment of artificial recharge impacts on the aquifer. Water levels would have been monitored continuously in all ten wells. In addition, water quality sampling for inorganic, bacterial, and suspended sediment parameters was proposed for eight domestic wells within a mile of the pilot injection facility. Specific conductance and suspended sediment concentrations would have been measured on a daily basis in the domestic and monitoring wells.

Funding for Phase A of the project was solicited through the Montana Department of Natural Resources and Conservation and was contingent on approval of State and Tribal agencies. Because the Confederated Salish and Kootenai Tribe had reservations about the artificial recharge project, funding for Phase A was used to update the groundwater-level and chemistry information throughout the valley and to determine if the artificial recharge concept was still viable based on current hydrogeological conditions. Phase B funding was proposed through the U.S. Bureau of Reclamation and was denied.

2.0 Present hydrogeological framework in relation to the proposed artificial recharge concept

The Lonepine aquifer was reappraised to evaluate hydrogeologic changes that may have occurred since it was characterized by Donovan (1985). A water-level monitoring program was re-instituted and continuous water-level data were compiled to examine groundwater trends from 1971 to present. A detailed comparison of groundwater levels and quality data collected between 1993 and 1995 to that collected between 1979 and 1982 was presented by Abdo (1997). Data and interpretations from Abdo (1997) are used in this report to compare groundwater quality from 38 wells completed in the Lonepine aquifer to surface water quality from the Little Bitterroot River and the canal system. Groundwater level trends examined by Abdo (1997) are also included in the this report.

2.1 Groundwater-level trends

Long-term hydrographs for monitoring wells 98, 196, and 211 are shown in Figure 5. The locations of these wells relative to the proposed recharge sites are shown in Figure 6. The hydrographs show short-term seasonal drawdown that results from increased groundwater withdrawals for irrigation during the summer months. Seasonal drawdowns are the smallest in wells 211 and 196 and range from approximately 3.0 to 9.0 feet. Annual water-level change in well 98, which is located in a heavily irrigated area, ranges from 7.0 to 13.0 feet. Groundwater drawdowns are greater south of well 98 (Figure 6) when compared to data northwest of this well. South of well 98 the valley narrows, the aquifer thins to approximately 20 feet, and transmissivity is lower (Abdo, 1997). In 1993, drawdown reached approximately 16 feet in this area.

Figure 5 also illustrates a general long-term decreasing trend in water levels for the period of record (1971 to 1995). Declines were from 0.7 to 1.1 feet per year from 1970 to 1977, and 2.0 to 2.5 feet per year from 1981 to 1985 (Donovan, 1985). Water levels declined between 0.8 to 2.6 feet per year from 1991 to 1995. The long term decline is interrupted with periods of two to five years of stable or increasing water levels. There is a correlation between precipitation and water-level trends with increased precipitation resulting in increases in the potentiometric surface (Figure 5). This increase is probably related to less groundwater withdrawals during wetter years

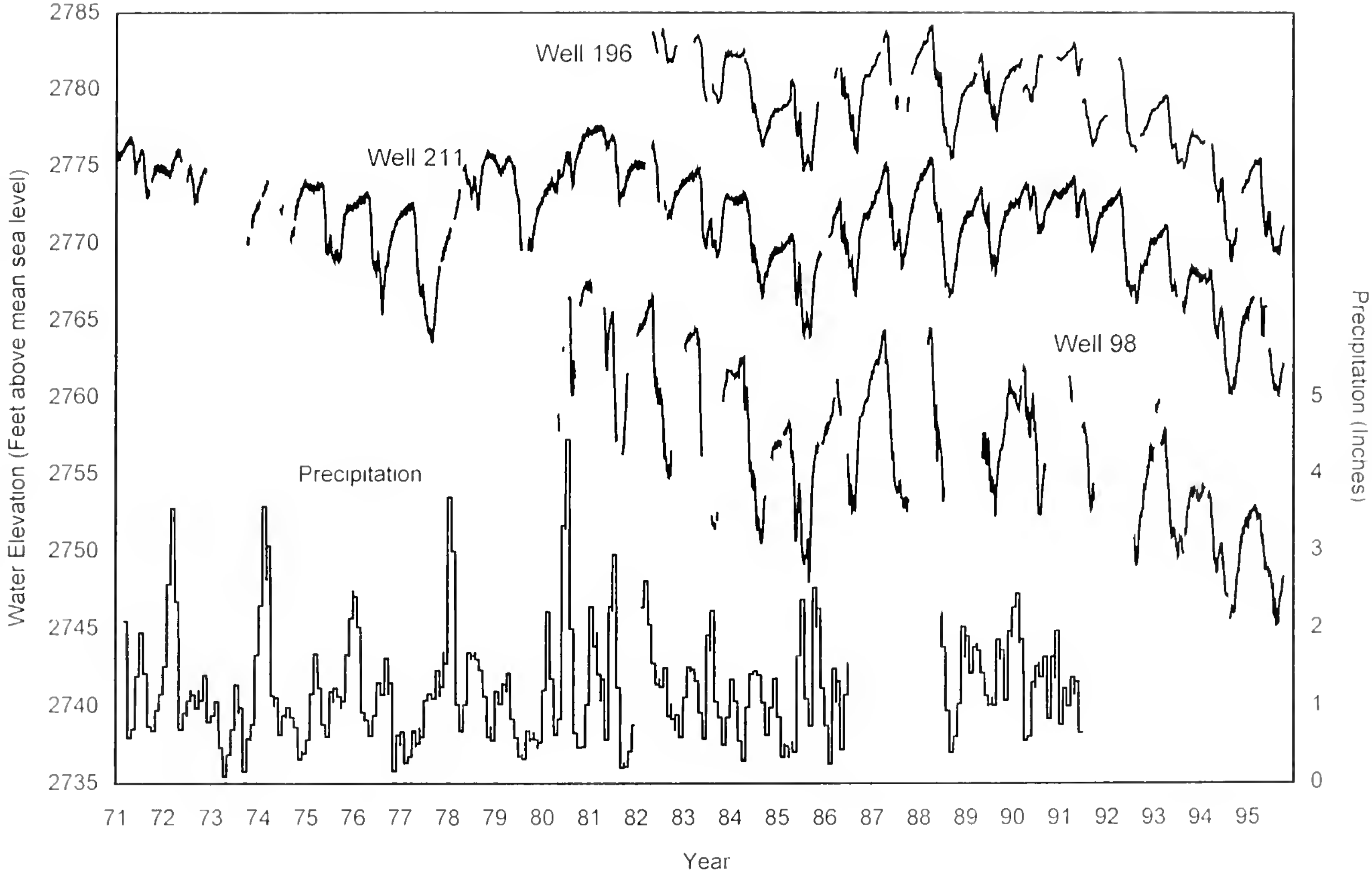

Figure 5. Groundwater hydrographs showing long-term trends in potentiometric levels and 3-month moving average precipitation rates.

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Figure 6. Locations of groundwater monitoring wells, sampling sites, and plugged wells.

and/or more recharge. In drier years, the lack of precipitation necessitates increases in groundwater withdrawals for irrigation, resulting in a lowering of the water level surface.

The continued long-term water-level declines indicate that aquifer pressures have not increased in recent years (1990-1995) and any measures to increase the potentiometric surface could benefit the hydrogeologic system.

2.2 Water availability for recharging the aquifer

Donovan and Noble (1986) proposed that surface water from the Little Bitterroot River could be made available for artificial recharge during years when springtime flows are above instream flow requirements (approximately 12 acre-feet/day) and when FIP reservoirs are full. He calculated that excess runoff above required instream flow would have been available for 6 years between 1975 and 1986.

Provisional surface water flow data was obtained from the gaging station on the Little Bitterroot River below Mill Creek (Confederated Salish and Kootenai Tribes, 1995). Table 1 indicates the amounts of springtime flow above instream flow requirements that would have been available from 1989 to 1995 for Donovan's proposed artificial recharge plan. These data indicate that from March to June, there was water available to supply Donovan's Phase A recharge proposal.

The amount of stream flow actually available depends on where the flow is measured. For instance, Abdo (1997) showed that during two different measurements (November 1993 and April 1994) the Little Bitterroot River lost water in the reach between the gaging station below Mill Creek (designated as LBR on Figure 6) and a point approximately 3 miles downstream. In this section of the river flows decreased by 55% during November 1993 and 70% during April 1994 through streambed losses. Therefore, it would depend on where streamflow is measured to determine if and how much surface water would be available for artificial recharge after in-stream flow requirements are met. Measurements at the diversion site would be necessary to determine actual availability but the proposed rate of 3 acre-feet/day would only be about 0.05% to 7% of surface water apparently available at the Mill Creek Gage based on the data presented in Table 3.

Table 1
Approximate total monthly stream flow (acre-feet per day) above instream flow requirements of the Little Bitterroot River.

Year	March	April	May	June
1989*	--	476	178	107
1990*	147	2300	238	981
1991	61	5784	4208	3712
1992	147	67	224	282
1993	162	77	59	79
1994	141	135	143	45
1995	119	0	0	0

* Total monthly stream flow amounts above instream flow requirements for 1989 and 1990 (March thru June) are based on partial monthly flow data.

Figure 7 shows the storage amounts in the Lower Dry Fork Reservoir from 1980 to present. The reservoir was full during nine out of the last 15 years. For four consecutive years however. (1992 to 1995) project reservoirs were not full. This period corresponds to years of lower precipitation. a time when groundwater levels were declining (Figure 5) and streamflows above instream flow requirements were at a minimum. Therefore. during a period when artificial recharge would have been most beneficial. excess water would not have been available.

2.3 Water quality

The State's Water Quality Act's nondegradation policy mandates that the quality of groundwater needs to be maintained and protected. Relative to this project. the recharge water would have to be of the same or better quality than the receiving groundwater. If surface water injection results in degradation of groundwater quality. authorization from the Department of Environmental Quality is required (Arrigo. 1995). This section examines surface water quality and how it relates to groundwater quality.

Thirty eight groundwater samples were analyzed for inorganic constituents as part of the hydrogeologic characterization of the area (Abdo. 1997). The location of the groundwater and surface water sampling sites are shown on Figure 6. Inorganic and organic analyses of samples from the Little Bitterroot River. and the A. B. and C canals were compared to groundwater

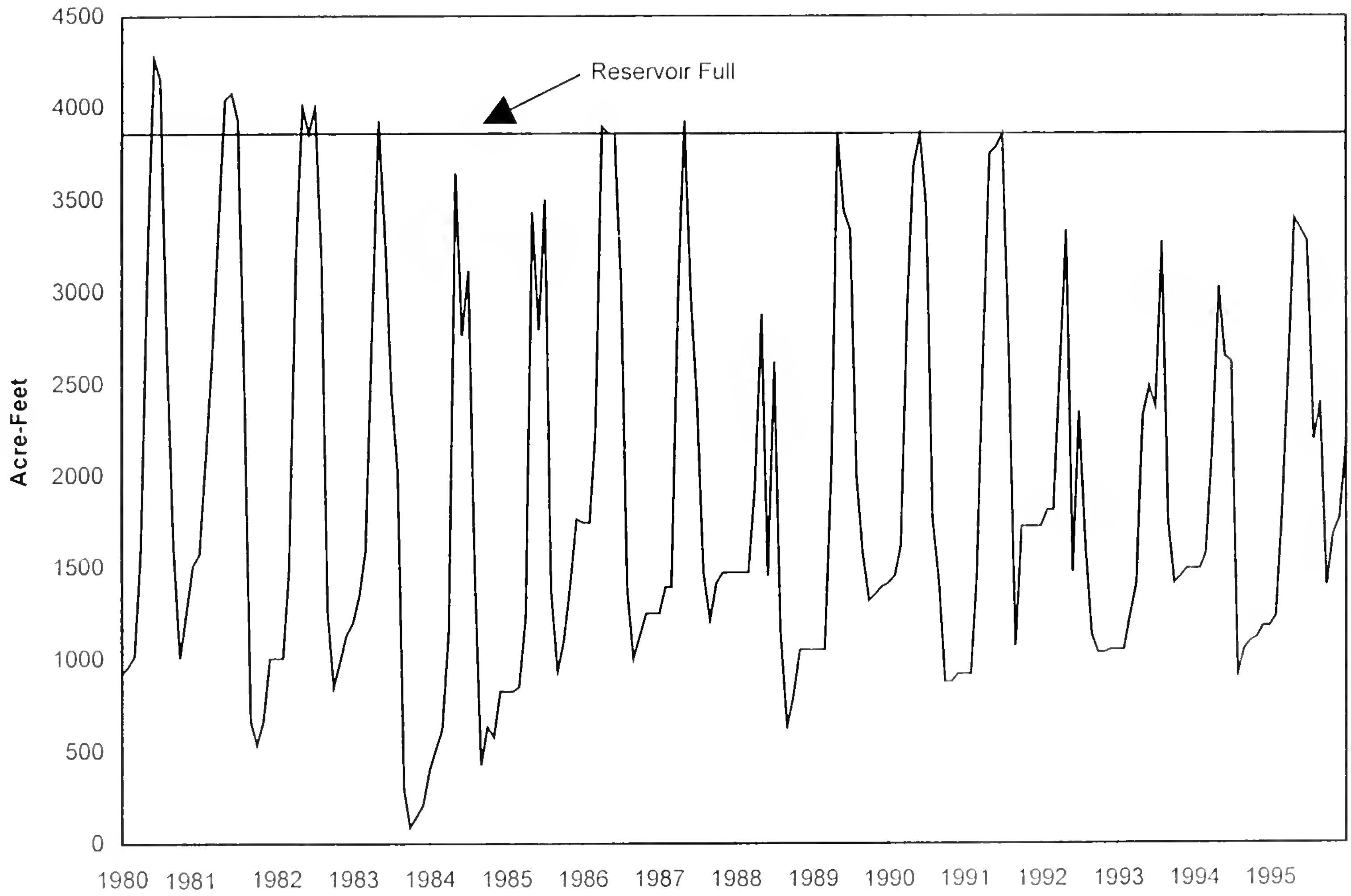

Figure 7. End-of-month storage amounts in the Lower Dry Fork Reservoir.

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quality in the Lonepine aquifer. In addition, groundwater from wells 211 and 292 was also analyzed for organic compounds. Surface water from the B-canal was sampled because it is the proposed source of water for Phase A of the artificial recharge project. B-canal samples were collected on June 2, 1993 and May 2, 1994. The May 2 sample was the first day the water flowed in the B-canal for the season and represents water quality as an initial flush through the canal. The source of water for Phase B would be from the Lower Dry Fork Reservoir. Dry Fork Reservoir water was collected from the C-canal immediately below the reservoir outlet and represents reservoir water chemistry. Organic analyses for Tordon, and 2,4,D were performed in order to identify impacts from the use of these pesticides/herbicides in the northern part of the valley. Water samples for bacterial analyses were also collected from the B and C canals in May 1994.

2.3.1 Inorganic analyses results

The results for the inorganic analyses obtained from the A, B and C Canals are presented in Table 2. Table 2 also includes the average, median and range of concentrations obtained from analyses of groundwater from 38 wells completed in the Lonepine aquifer. Groundwater quality from well 211 is also presented since this is the injection well proposed for phase A. Overall, comparison of the groundwater to surface water quality shows that for most of the constituents analyzed, surface water concentrations fell within the range of the groundwater concentrations. Sodium, bicarbonate, fluoride and total dissolved solids were lower in surface water then in the groundwater.

The concentrations were higher for most constituents in groundwater from well 211 when compared to the surface water. However, the potassium concentration was lower and nitrate was about the same in groundwater when compared to surface water. Groundwater concentrations of cadmium, copper, lithium, molybdenum, nickle, lead, silver, titanium and vanadium concentrations were below the instrument detection limit.

Lead and copper concentrations varied in the samples from the canal system. A lead concentration of 7.3µg/l was present in the B-canal sample collected on June 2, 1993. However, the lead concentration obtained from the B-canal on May 2, 1994 was below the instrument

Table 2

Water Quality (groundwater concentrations were from 38 wells).

Sample Name	Water Quality No	Sample Date	GWIC Number	Sample Type	Water Temp	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Silica (mg/l)	Carbonate (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)
A - CANAL	93Q0722	2-Jun-93	M 140373	Dissolved	13.8	10.7	2.7	5.5	1.3	0.05	0.02	16.1	0	54.9	1.4
A - CANAL	93Q0737	2-Jun-93	M 140373	Total	13.8	11.7	2.8	6.2	1.4	0.21	0.03				
B - CANAL	93Q0716	2-Jun-93	M 140372	Dissolved	14.5	11.2	2.7	5.5	1.6	0.04	0.02	16.7	0	55.7	1.5
B - CANAL	93Q0738	2-Jun-93	M 140372	Total	14.5	11	2.6	5.9	1.5	0.19	0.02				
B - CANAL	94Q0985	2-May-94	M 140372	Dissolved	16.9	9.3	2.4	5.9	3.5	0.08	<.002	18.6	0	50.3	1.3
C-CANAL	94Q0984	2-May-94	M 141773	Dissolved	18.3	12.1	3.4	11.8	2.0	0.09	0.01	12.0	0	71.2	1.6
Groundwater Range				Dissolved	9.0-47.9	2.4-65.7	0.1-18.1	19.3-156.0	0.8-6.5	<0.003-1.3	<0.002-0.9	11.5-44.5	0-3.6	105.0-359.5	1.7-35.6
Groundwater Average				Dissolved	18.9	18.0	4.8	81.4	2.2	0.31	0.22	24.1	NA	250.0	14.2
Groundwater Median				Dissolved	16.4	9.6	2.4	88.1	2.0	0.17	0.11	21.0	NA	249.0	10.0
WELL 211	93Q0720	2-Jun-93	M 6283	Dissolved	14.4	39.9	10.4	34.4	1.5	1.01	0.66	21.0	0.0	238.0	4.9

Sample Name	Water Quality No	Sample Type	Sulfate (mg/l)	Nitrate as N (mg/l)	Fluoride (mg/l)	Phosphate (mg/l)	Aluminum µg/l	Arsenic µg/l	Boron µg/l	Barium µg/l	Cadmium µg/l	Chromium µg/l	Copper µg/l	Lithium µg/l	Molybdenum µg/l
A - CANAL	93Q0722	Dissolved	6.0	0.07	0.21	<.02	80	<1	<30	26.7	<2	<2	<2	<6	<20
A - CANAL	93Q0737	Total						<1		32.0	<2	<2	4.9	<6	<20
B - CANAL	93Q0716	Dissolved	6.2	<.04	0.20	<.02	<100	<1	<30	28.1	<2	<2	43.0	<6	<20
B - CANAL	93Q0738	Total						<1		30.7	<2	<2	13.0	6	<20
B - CANAL	94Q0985	Dissolved	4.8	0.102	0.13	<.025	59.1	<1	<30	21.5	<2	<2	<2	<6	<10
C-CANAL	94Q0984	Dissolved	9.0	<.1	0.17	<.025	<30	<1	<30	29.1	<2	<2	<2	<6	<10
Groundwater Range		Dissolved	<0.7-40.0	<0.04-1.9	0.4-7.5	<0.1-2.2	<30	<1.0-110.0	<30.0-810.0	10.4-1675.0	<2	<2	<2	<6.0-93.0	<20
Groundwater Average		Dissolved	7.8	0.16	3.90	NA	BD	22.9	377.4	405.6	BD	BD	BD	29.4	BD
Grondwater Median		Dissolved	5.9	0.03	3.70	<0.1	BD	9.8	353.0	262.0	BD	BD	BD	16.0	BD
WELL 211		Dissolved	10.7	0.05	1.00	<0.1	<100	3.3	56.0	516.0	<2	<2	<2	<6.0	20

Sample Name	Water Quality No	Sample Type	Nickel µg/l	Lead µg/l	Silver µg/l	Strontium µg/l	Titanium µg/l	Vanadium µg/l	Zinc µg/l	Zirconium µg/l	TDS (mg/l)	Lab pH	Field pH	Lab SC µmhos/cm	Field SC µmhos/cm
A - CANAL	93Q0722	Dissolved	<2	<2	<1	52	<10	<5	<2	<50	71.1	7.97	8.48	109	97
A - CANAL	93Q0737	Total	<2	<2	<1	55	<10	<5	3	<50			8.48		97
B - CANAL	93Q0716	Dissolved	<2	7.3	<1	53	<10	<5	<2	<50	73.0	7.9	8.15	110	95
B - CANAL	93Q0738	Total	<2	<2	<1	52	<10	<5	<2	<50			8.15		95
B - CANAL	94Q0985	Dissolved	<2	<2	<1	47	<10	<5	<2	<20	70.9	7.38	8.73	91	107
C-CANAL	94Q0984	Dissolved	<2	<2	<1	63	<10	<5	<2	<20	87.3	7.45	7.02	130	130
Groundwater Range			<2	<2	<1	14.0-294.0	<10	<5	<2-104.9	<50	176-602	6.7-8.8	6.7-8.8	290-708	275.0-723.0
Groundwater Average			BD	BD	BD	105	BD	BD	15.9	BD	287.0	NA	NA	475	445
Groundwater Median			BD	BD	BD	107	BD	BD	8.0	BD	267.0	NA	NA	453	421
WELL 211		Dissolved	<2	<2	<1	160	<10	<5	13.3	<50	362.0	8.03	7.97	411	380

NA Not Available BD All values below instrument detection limit

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detection limit. Groundwater lead concentrations for samples collected between 1993 and 1994 were below the detection limit (2.0 μg/l). A copper concentration of 43 μg/l was present in the B-canal sample collected on June 2, 1993 and was below the detection limit in the sample collected on May 2, 1994. Copper concentrations for groundwater samples collected between 1993 and 1994 were below the detection limit (2.0 μg/l). Lead and copper concentrations in the June 2, 1993 surface water samples were significantly below the action level established for lead (15 μg/l) and the secondary maximum contaminant limits for copper (1000.0 μg/l).

The concentrations of inorganic constituents analyzed in surface water suggest that introduction of surface water into groundwater would probably not degrade groundwater quality. However, some water quality factors may be pertinent to the long-term success of the artificial recharge plan. These include the presence of suspended sediment and entrained air in the recharge water, and the potential for iron precipitation. Donovan and Noble (1986) proposed to remove sediment in the recharge water with a sediment removal gallery (Phase A) and by settling (Phase B). Entrained air in the recharge water would be minimized by injecting the water without aeration or cascading of water. However, if these methods are not adequate, sediment and entrained air can cause clogging of the recharge well. Iron precipitation can occur if iron -rich water is exposed to oxidizing conditions (in this case the recharge water would be in an oxidized state) and can result in clogging of the aquifer (O'Hare and others, 1986). Groundwater sampled from well 211 (pilot injection well - Phase A) is in a reduced state and has a dissolved iron concentration of 1.0 mg/l. Therefore introducing surface water, which is oxidized, into the well has a high potential to result in iron precipitation. Changes that may be produced in the water chemistry can also promote biological growth which can limit the long-term success of artificial recharge.

2.3.2 Organic analyses results

A phenoxy scan (EPA Method 515.2) performed by Montana State University, Agricultural Experiment Station Analytical Laboratory, indicated that concentrations of organic constituents in all samples were below the method detection limits. The sampling sites, dates and method detection limits are shown in Table 3.

Table 3
Organic constituents analyzed as part of the phenoxy scan
(all constituents were below the method detection limits).

Site	Date	MCPP	Triclopyr	2,4,5-T	2,4-DP	Clopyralid	Picloram	Dicamba	MCPA	2,4-D	PCP	Dinoseb	Silvex
A-Canal (A1)	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
A-Canal (A2)	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
B-Canal	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
	5/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
C-Canal	5/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
Little Bitterroot River	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
Well 211	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2
Well 292	6/2/93	<2.6	<0.25	<0.2	<0.3	<1.0	<0.4	<0.3	<2.6	<0.3	<0.2	<0.3	<0.2

The absence of organic compoundss in the surface water samples indicates that they were not present at the time of sampling. This does not necessarily preclude their presence in groundwater. They may be present during times of high pesticide/herbicide use or flushed through the system during precipitation events. Mechanisms such as degradation and attenuation can remove or alter the organic constituents from the groundwater system. However, due to the deep confined nature of the aquifer, it is unlikely to find pesticides/herbicides in the groundwater.

2.3.3 Biological concerns

Total coliform bacteria, which includes fecal coliform bacteria, were present in two samples collected from the B and C Canal in May 1994. Bacteria present in the recharge water can result in microbial growth in the recharge well. This can clog the well and aquifer, therefore, reducing the transmissivity in the aquifer and increasing water level buildup in the well (O'Hare and others, 1986). The identification of coliform bacteria also indicates that pathogens may be present in the water

Two common viruses that are often present in surface water and effect cattle in the Little Bitterroot Valley are bovine virus diarrhea and leptospirosis (Marrinan, 1995). Surface water sampling for viruses was not performed during this study. However, studies show that viruses

can survive in groundwater. If viruses are present in surface water they may potentially be transported into the groundwater system via artificial recharge.

Bovine virus diarrhea causes fever, cough, diarrhea, dehydration, inflammation of the mucous membranes and lesions on the lymphatic tissues. This virus suppresses the immune system of a cow and can result in abortion and breeding problems (Baker, 1987). Leptospires can cause fever, yellowing of the skin, and bloody urine and milk. These viruses are transported by water and potentially exist in the Little Bitterroot River, it's tributaries and the irrigation canals. Several studies of leptospires indicate that they are able to survive longer in alkaline water than in acidic water (Chang et al., 1948; Smith and Turner, 1961, Sawyere and Bauer, 1928). Balows and others (1991) found leptospires can survive up to 3 months or longer in neutral or slightly alkaline waters.

Survival of viruses in groundwater depends on a number of factors including the type of virus, groundwater temperature, dissolved oxygen content and the presence of microorganisms (Jansons and others, 1989). Lower groundwater temperature and dissolved oxygen have been associated with increases in the survival rate of viruses in groundwater (Jansons and others, 1989). The presence of a bacterial population has also been associated with a decline in viruses.

3.0 Groundwater wastage

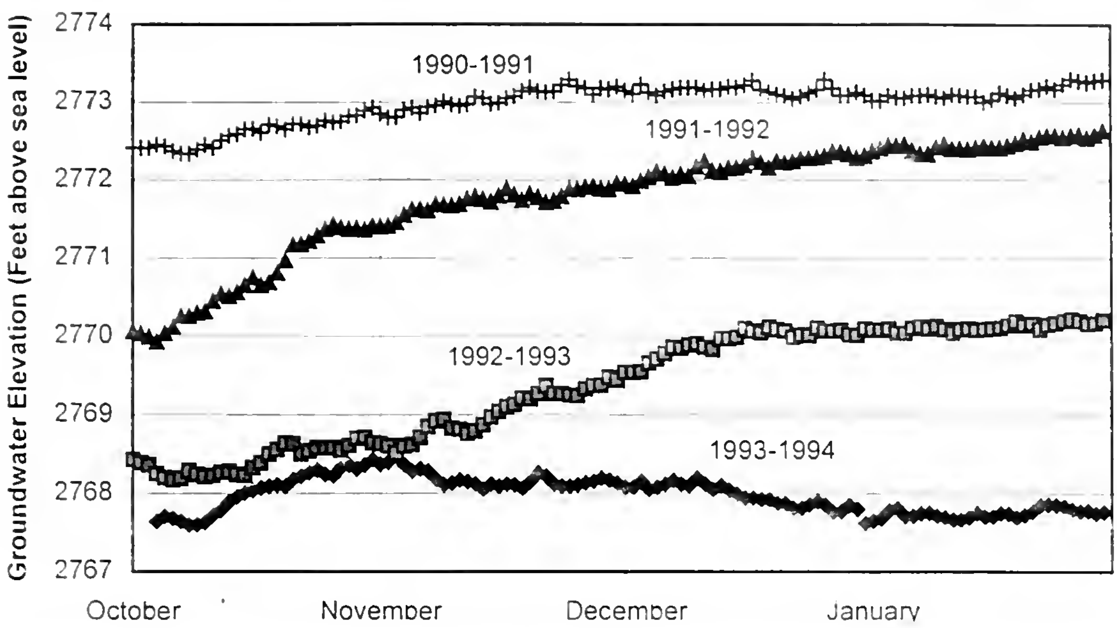
There are approximately 72 flowing wells, many of which were installed in the early to mid 1900's, between Lonepine and Oliver Gulch. Casing corrosion, inadequate well seals, defective valves and no valves at all result in leakage from some of these wells even when thought to be shut-in. Of the 40 wells visited (Abdo, 1997), approximately 10% exhibited surface leakage ranging from less than 1 to 5 gallons per minute (gpm). Extrapolating this information to all 72 wells, it is estimated that surface leakage results in a loss of about 30,000 gallons per day (gpd) from the system. This value is conservative because some leakage most likely occurs below the ground surface and is not visible. Although leakage from faulty well construction is a problem, an even greater volume of water is wasted from uncontrolled discharge of several wells. These discharge amounts varied from about 1 to 40 gallons per minute. It is estimated that at one time or another about 17 of the 40 wells (42%) were flowing for no apparent reason (i.e. no cattle were around, it was not the irrigation season). Wells were also flowing to fill reservoirs even

though the reservoirs were already full. Another major contribution to unnecessary flows occurs during the winter months when wells are allowed to flow at amounts greater than necessary to prevent wellheads from freezing. Extrapolating these wastage amounts to all wells and assuming that all unnecessary flows were occurring at the same time, about 470,000 gpd of groundwater was wasted in 1994 - 1995. Some of this groundwater wastage has been observed to flow into the Little Bitterroot River.

A prime example of the impact of groundwater wastage occurred on November 3, 1993 -- a split in the steel casing of a well drilled in the 1940's resulted in accidental breaking of the wellhead. For a period of at least two months, approximately 300 gpm flowed uncontrolled. Figure 8 shows the response in the hydrogeologic system from October 1993 through January 1994 at well 211, approximately 4.5 miles northwest of the uncontrolled flowing well. Water level declines within the first month of uncontrolled flow (November 1993) ranged between about 0.7 to 1.4 feet. In early December 1993 water level declines appear to steepen a second time. This may be the result of the cone of depression, created by the uncontrolled flowing well, reaching a barrier boundary -- in which case an even greater decline occurs in the system. Groundwater elevations shown on Figure 8 illustrate that normally, during this time of year, groundwater levels are rising.

4.0 Groundwater conservation

Conservation of water resources in the form of controlling unnecessary flows can have a beneficial effect on increasing aquifer pressures and water levels and provides a viable alternative to artificial recharge. Flow control is illustrated by the plugging of two wells, which had flowed uncontrolled before being sealed in the mid to late 1980's. The location of these wells (wells 24 and 76) are shown on Figure 6. The date of sealing well 24 is unknown. Well 76 was sealed on December 4, 1986 after many years of uncontrolled flow between 300 to 500 gpm. Water level data obtained from monitoring wells 98, 196 and 211 show that water levels rose in response to the plugging of well 76. Water levels for these wells over a four month period, extending before and after well 76 was plugged, are shown in Figure 9. Well 98, located approximately 1.7 miles south of well 76, shows the response most clearly. In well 98, water levels rose between 1.0 and 1.5 feet in the weeks following December 4, 1986. Water levels also



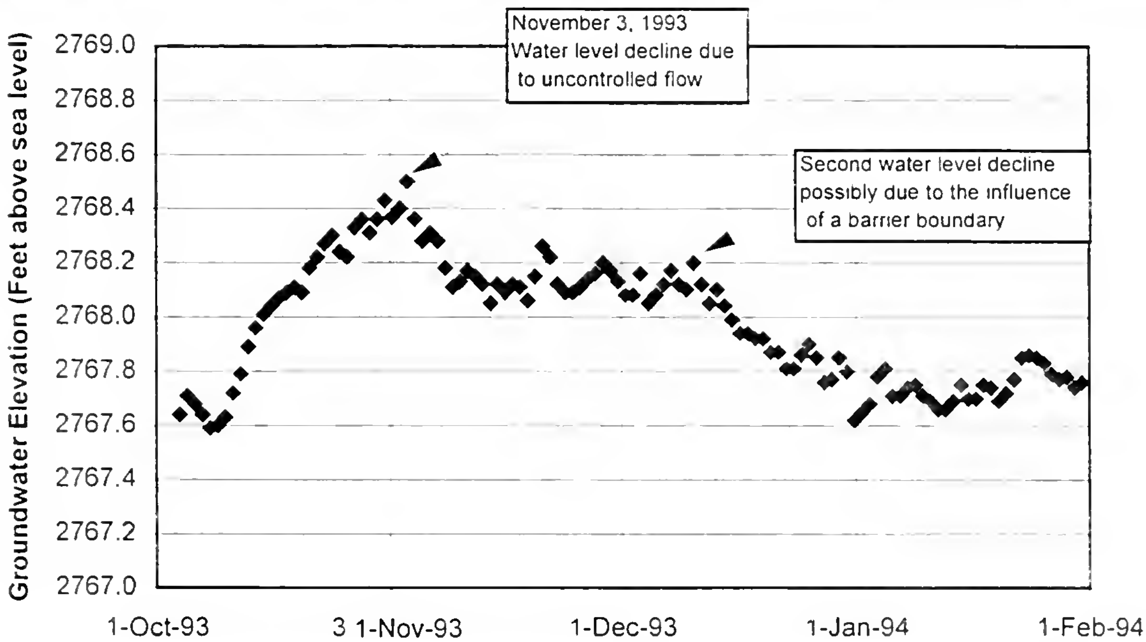


Figure 8. Groundwater hydrographs from monitoring well 211 (located 4.5 miles northwest of the uncontrolled flowing well) showing the response in the Lonepine aquifer from October through January 1990 - 1991, 1991-1992, 1992-1993 and 1993-1994. The lower hydrograph is more detailed to show the effects of uncontrolled groundwater flow on the hydrogeologic system.

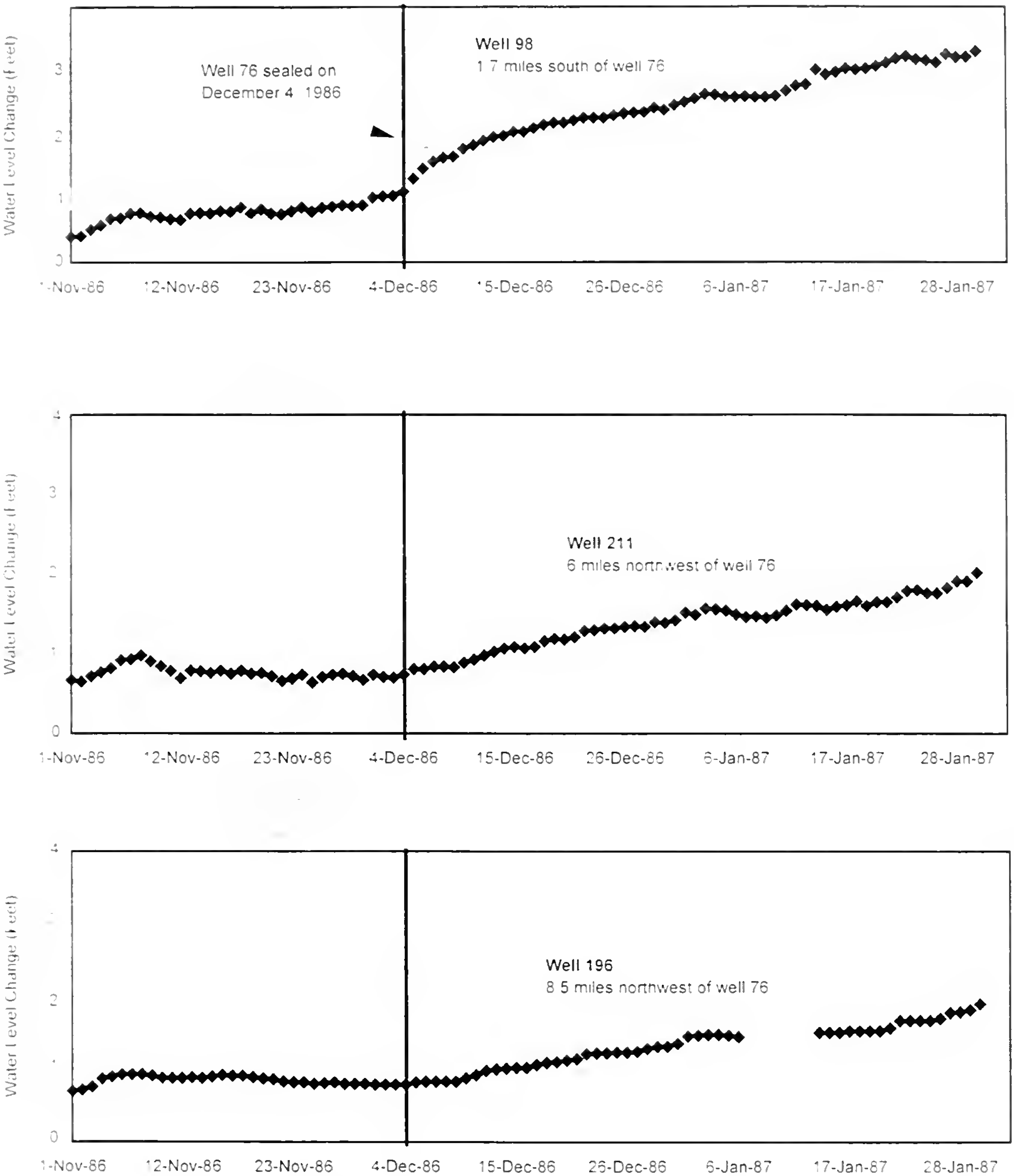


Figure 9. Water level responses in wells 98, 196, and 211 to sealing well 76 on December 4, 1986.

rose in wells 211 and 196 (located approximately 6.0 and 8.5 miles northwest of well 76, respectively) although the increase was not as obvious as that in well 98. Water levels increased by about 0.8 to 1.2 feet in well 211 and 0.7 to 1.0 in well 196.

Water level recovery at any time after the end of the discharging period is theoretically identical to the drawdown at the same time during the discharging period (Driscoll, 1986). Based on this concept, a technique presented by Lohman (1979), which assumes a constant discharge and variable drawdown was used to estimate the effects of discharge on drawdown as a function of distance from the discharging well (in this case well 76). These results were then converted into hypothetical recharge rates (which represent conservation rates) and associated water-level recoveries.

Water-level data from monitoring well 98, obtained after well 76 was sealed, yielded a estimated transmissivity of 19,000 ft^2/day and a storativity of about 0.0004 at an approximate recharge rate of 400 gpm. Using this information, Figure 10 shows extrapolated values of recovery amounts at various distances from well 76 under different rates of recharge-- and can be used as an estimate of the effects of groundwater conservation. This effect is estimated at 1, 5, 10 and 15 years. For example, Figure 10 indicates that after a ten year period, conserving 200 gpm of groundwater would result in an increase of the potentiometric surface by about 1.5 feet at two miles from the conserving well. These graphs show that at a given point in time and at a constant conservation rate, recovery is greatest closer to the conserving well. As conservation amounts increase, so does recovery. At some time, the difference in recovery at a constant conservation rate between time periods becomes minimal; for example, there is little difference in recovery between 10 and 15 years.

Groundwater conservation occurring in more than one well at a time will result in recovery amounts greater than that estimated in Figure 10. Given the direct relationship between conservation and recovery, any conservation of groundwater will conserve pressures; the doubling of one will double the other.

4.1 Winterizing flowing wells

As discussed above, unnecessary groundwater discharges occur when wells are kept flowing during the winter months because the owners believe that this will prevent damage to the

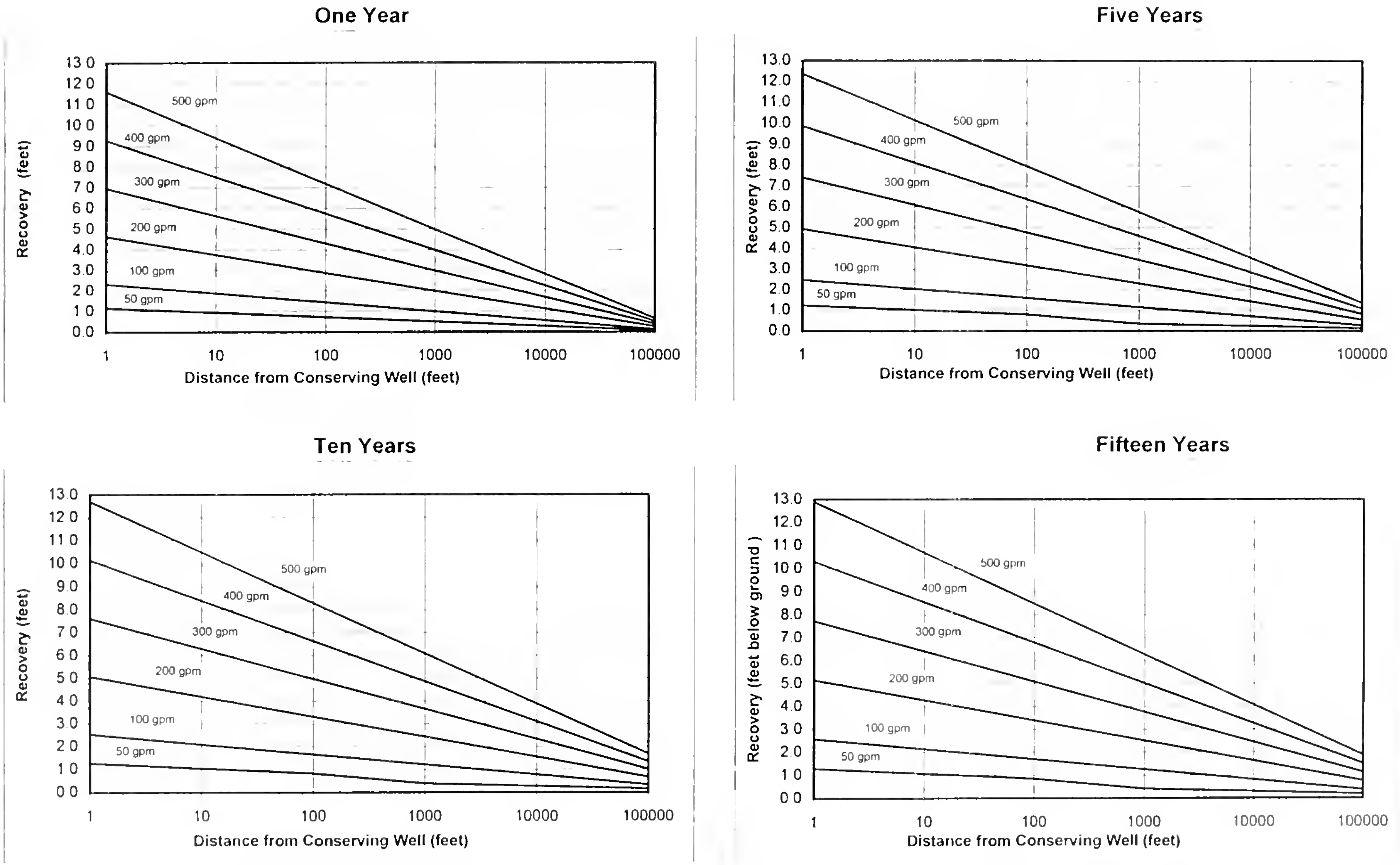


Figure 10. The effects of varying conservation rates on groundwater recovery at different distances from the conserving well after one, five, ten and fifteen years.

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wellhead from freezing. Some ideas to decrease or eliminate groundwater wastage attributed to flowing wells during the winter months are:

1. Restrict flow to a minimal amount (i.e. 5 gpm as opposed to 40 gpm).
2. The use of inflatable packers to seal water off below the frost line. The water that remains above the packer can be removed with a pump.
3. Complete new wells in a pit approximately 5 to 8 feet below ground (below the frost line).
4. Install a T valve below the frost line with surface access to turn the valve on or off. In this case, there would be no wellhead above the ground.
5. Install an air valve on the flowing wells so that air injected into the well will depress the water level below the frost line.
6. Use hay bails or a small shack to insulate the wells.

4.1 Conserving water through efficient irrigation practices

Surface and groundwater conservation can also be achieved by improving the efficiency of irrigation practices. This form of conservation can lessen groundwater withdrawals. Information contained in this section was supplied by the Natural Resource Conservation Service (Feist, 1996).

Irrigation efficiency can be improved by use of structural and management practices. Structural practices include replacing surface ditches with buried main lines and lining leaky ditches. This will decrease evaporation and loss of water through leakage and can result in saving up to 60 percent. This means that less water would need to be withdrawn for irrigation.

Irrigation management practices refer to the timing and application of irrigation water. Monitoring soil moisture conditions and applying only enough water to meet plant needs can result in savings of 10 to 20 percent. Meeting plant needs in eight hour sets as opposed to twelve hour sets can result in a water savings of 33 percent.

Managing equipment efficiently can also result in water conservation. Leaky delivery systems can lose up to 30 percent of the water before it is applied to the field. Sprinkler nozzles need to be the same size for the entire sprinkler. Wrong nozzle sizes and worn nozzles that are 1/64 inches oversized will increase discharge by 20 percent. Sprinklers supplied from wells are less likely to have excessive wear but canal water can wear nozzles at a rapid rate. However, in

areas of the valley where groundwater chemistry is influenced by the geothermal system, elevated concentrations of hydrogen sulfide can increase corrosion rates resulting in substantial wear. Drill bit shanks that are the same size as the nozzles can be used to tell how badly a nozzle is worn. A shank placed into a nozzle that is not worn will leak a minimal amount of water. Savings of 10 to 30 percent could decrease groundwater withdrawals and lessen drawdown in wells.

5.0 Summary and recommendations

Long-term groundwater declines show that withdrawals exceed recharge to the Lonepine aquifer. Groundwater conservation can increase water levels in the aquifer and is a cost effective alternative to artificial recharge. Repairing leaky valves, reducing excess flow when water is being wasted and shutting wells in when water is not being put to beneficial use are the best means to conserve water. Techniques to either insulate the wellhead, install valves and/or seal groundwater off below the frost line can also enhance groundwater resources by eliminating groundwater discharges that are used to prevent damage to the wellhead during the winter months. Educating well owners on the benefits of conservation and techniques to implement groundwater best management practices will help ensure that groundwater supplies are available for the future.

Artificially recharging the aquifer is another means to increase water levels in the Lonepine aquifer, however, compared to groundwater conservation, the costs may be prohibitive. It appears that in drier years when more groundwater is utilized, there may not be sufficient supplies to artificially recharge the aquifer. The DNRC requires a permit to take surface water and apply it to groundwater. This would entail providing information that substantiates that there is enough water in the river to be withdrawn, and that this would result in no adverse impacts to downstream users. Therefore, a detailed investigation of surface water flow amounts would be necessary. Information would also need to be provided that supports a beneficial use of the surface water.

Initial surface water quality analyses indicate that most constituents fall in the same range or below groundwater chemical concentrations and therefore, would not degrade groundwater quality. Assuming that suspended sediment would adequately be removed from the surface

water, biological factors need to be examined. Bacteria and viruses most likely exist in the surface water system. If surface water is introduced into groundwater, the potential exists for the transport of these organisms in the subsurface. Redox reactions related to mixing waters of different oxidation states may produce changes in chemistry that can result in microbial growth and iron precipitation in the well. Microbial growth can result in clogging of the recharge wells, thereby, reducing the efficiency of artificial recharge.

Groundwater conservation is a practical cost effective means to improve groundwater conditions. However, it does involve the well owners to take responsibility for implementing and participating in a groundwater conservation program. A watershed committee formed of citizens of the area, county, state and tribal representatives would be the best way to keep individuals current on groundwater and surface water issues and can lead to best management practices that will enhance water resources.

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